Semi-Annual Progress Report

July 1999

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Task Objectives

The objectives of the last six months were:

- Continue analysis of Hawaii Ocean Time-series (HOT) bio-optical mooring data,
- Continue analysis of bio-optical from JGOFS cruises in the Southern Ocean
- Revise Algorithm Theoretical Basis Document
- Prepare for MODIS validation cruise off California and Mexico
- Develop plan for MODIS Direct Broadcast facility
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors.
- Continue to develop and expand browser-based information system for in situ bio-optical data

Work Accomplished

Analysis of Field Data from Hawaii

We continue to analyze bio-optical data collected at the Hawaii Ocean Time Series mooring. The HOT bio-optical mooring was recovered in May 1999. After retrieving the data, the sensor package was serviced and redeployed. Unfortunately, there had been an electrical failure midway through the deployment so the record was short. We now have over 30 months of data. These are being analyzed as part of a larger study of mesoscale processes at this JGOFS time series site. A manuscript documenting the effects of mesoscale circulation on productivity (as revealed by sun-stimulated

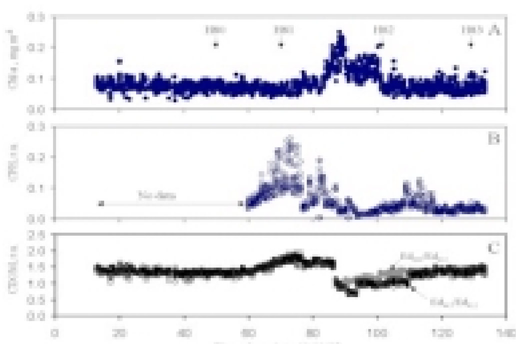

Figure 1 Temporal variations in (A) chlorophyll a concentration, (B) Chlorophyll Fluorescence Efficiency (CFE), and (3) Colored Dissolved Organic Matter (CDOM) in the upper 25 m of the water column derived from moored spectrophotometric time-series measurements and observations between January and May 1997.

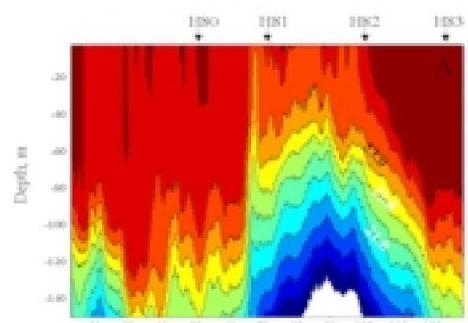

Figure 2 Time-series displaying (A) 0-150 m depth distribution of temperature recorded by moored thermistors deployed at 2, 38, 50, 60, 80, 100, 120, 130 and 150 m

fluorescence) has been submitted to *Deep-Sea Research*, and we are awaiting the reviews.

Continuous records of upper water column (0-150 m) temperature structure, spectral distribution of downwelling irradiance and phytoplankton solar-induced fluorescence at 25 m depth have been obtained in the vicinity of the Hawaii Ocean Time-series (HOT) Station ALOHA (22°45'N; 158°00'W) since January 1997. Two events displaying a strong increase in surface (0-25 m) chlorophyll concentration have been recorded by our spectroradiometers. The first event occurred in March-April 1997 (Figure 1) and appears to be associated to a strong upwelling event (Figure 2, Letelier et al. submitted). The second event took place in the middle of the summer (Figure 3) and was neither associated with an upwelling, nor with a deep mixing event.

During March-April 1997, the temperature record showed a strong upwelling event, displacing the thermocline upward by 120 m. This displacement was also recorded during the HOT program monthly

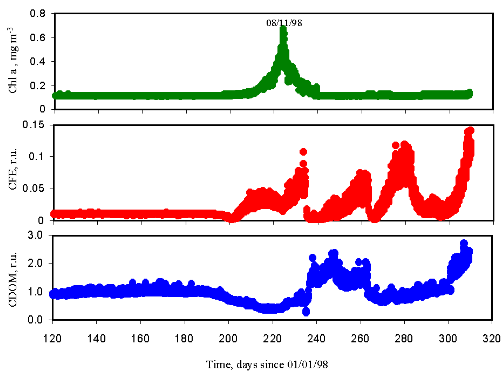

Figure 3 Same as Figure 1 but for the period May-November 1998.

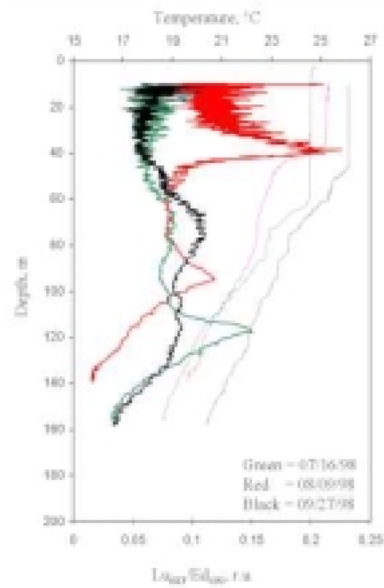

Figure 4 Vertical distribution of chlorophyll fluorescence per unit downwelling irradiance (thick lines) and temperature (thin lines) at Station ALOHA during July, August and September 1998.

sampling cruises (data not shown). At the onset of this upwelling event, increases in colored dissolved organic matter (CDOM) and chlorophyll fluorescence efficiency (CFE) in the upper water column were detected by changes in the spectral distribution of the downwelling irradiance. These increases suggest the upward displacement of dark adapted water masses. However, the increase in phytoplankton biomass, as estimated by chlorophyll a (Chl a) concentration, had a lag period of 14 days from the beginning of the upwelling event, suggesting that there was no direct input of nutrients into the upper 25 m of the water column. Nevertheless, the 0-25 m mean Chl a concentration increased three-fold (from 0.07 to 0.26 mg Chl a m^{-3}) toward the end of the upwelling period. The increase in CFE detected during this event is consistent with algal physiological stress resulting from a sudden increase in light availability without a concomitant increase in nutrient availability.

The increase in surface chlorophyll concentration observed during August 1998 has very different characteristics than the March-April 1997 event. For example, we do not see an increase in either CFE or CDOM early in the bloom. This observation suggests that the bloom was not associated to a vertical displacement of water and a physical transport of nutrients. Preliminary analyses of the temperature record indicate that, although there was a doming of isopycnals at depth, there was no significant change in the temperature structure of the upper fifty meters during July and August 1998. The increase in CFE took place toward the end of the bloom and may be the result of a change in nutrient availability during the senescence of the bloom. Vertical profiles of natural fluorescence prior, during, and after this summer bloom indicate that a distinct maximum fluorescence per unit of available light was located at the base of the mixed-layer during early August (Figure 4). This feature at the base of the mixed-layer is consistent with the accumulation of photoautotrophs with the capacity of regulating their buoyancy and/or fix di-nitrogen during stratified periods, such as *Trichodesmium* spp. and *Hemialus* spp. If our interpretation is correct, the observed summer bloom was the result of an increase in algal biomass fueled by nutrients transported actively from the base of the euphotic zone by vertically-migrating phytoplankton.

Our field observations to date appear to support the notion that surface CFE, when combined with CDOM, Chl a and temperature estimates will provide a valuable indication of changes in the physiological state of phytoplankton populations. Analyses of the temporal evolution of these parameters will help to distinguish different types of phytoplankton bloom events, such as the ones described above.

In addition, Ricardo Letelier is funded as part of the SeaWiFS calibration/validation effort (through a subcontract from the University of Hawaii, Dr. John Porter), and he is collecting bio-optical and fluorescence data as part of the HOT activity. This will provide additional in situ measurements for MODIS validation. All of these data may be obtained at our Web site, http://picasso.oce.orst.edu/users/jasmine/ORSOO . The data continue to be provided to the SIMBIOS project.

Analysis of Data from the Southern Ocean

We presented and discussed our results from the U.S. JGOFS Southern Ocean to the 31st International Liège Colloquium on Ocean Hydrodynamics in Belgium. Figure 5 shows the SST record from the November 1997 deployment. The record (Figure 5) shows a general increase in SST over the season, as expected. There is considerable correlation between the individual records, despite the fact that the individual drifters are sometimes separated by 100's of kilometers. For example, note the increase in temperature for several days beginning on 14 January 1998. The increase is consistently observed in every drifter although the drifters spanned a latitudinal distance of nearly 200 km. Figure 6 shows chlorophyll from the same drifter deployment, and Figure 7 shows the mean chlorophyll record for all of the drifter deployments. As with the mooring data from our last report, the chlorophyll patterns reveal a pronounced spring bloom early in the deployment followed by a slow decline over time. One drifter traveled far to the east and showed an increase in chlorophyll in the fall. Since this drifter was in the vicinity of the Pacific/Antarctic Rise at the time, we suspect that this increase was the result of increased mesoscale eddy activity and subsequent nutrient input.

Of particular interest for MODIS research is Figure 8 which shows the mean apparent quantum yield of fluorescence derived from all of the drifters. The approach was documented in an earlier report and subsequently published in Letelier et al. (1997). Note that the fluorescence quantum yield is low during the bloom in December and then increases as the bloom decays. The record becomes more variable as the number of drifters decreased as the centroid of the remaining drifter cluster moved closer to the Pacific/Antarctic Rise. This pattern and its relationship to chlorophyll concentration further confirms our approach to modeling primary productivity.

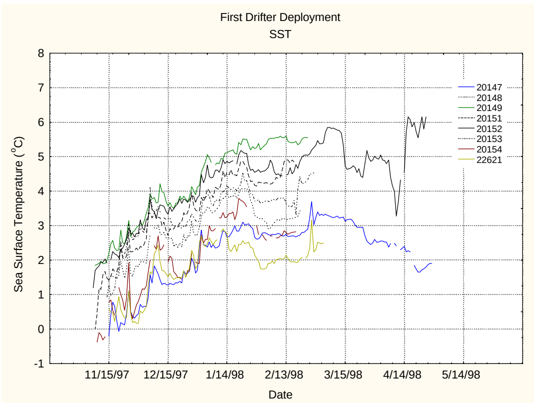

Figure 5. SST from the first drifter deployment in November 1997 in the Southern Ocean.

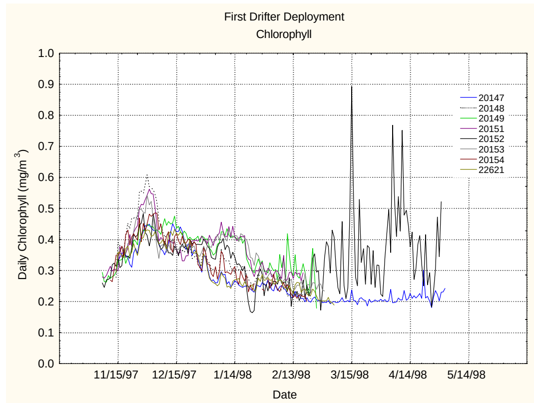

Figure 6. Chlorophyll from the first drifter deployment

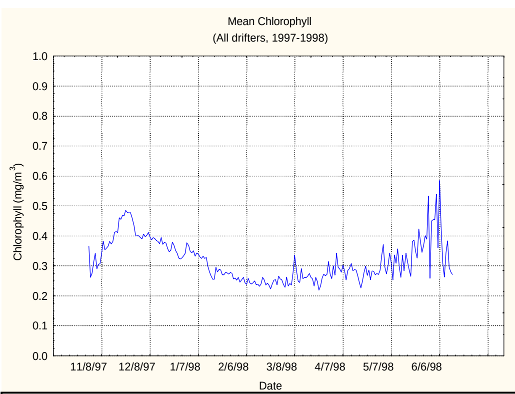

Figure 7. Mean chlorophyll concentration from all drifter deployments in the Southern Ocean, 1997-1998.

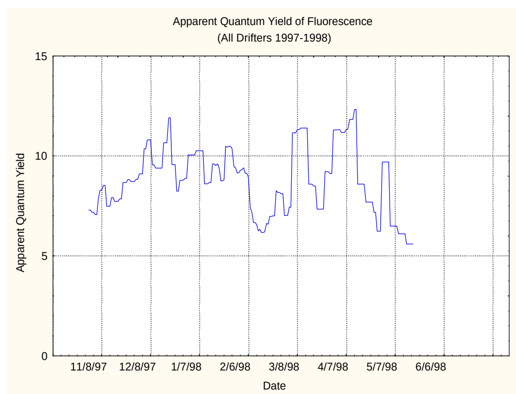

Figure 8. Mean apparent quantum yield of fluorescence in the Southern Ocean.

We collected 400 surface samples for detailed pigment analysis. Figure 9 shows chlorophyll concentrations derived from the HPLC analysis. Although it was cloudy during the survey, SeaWiFS imagery from four days after completion of the survey (not shown) confirmed the general pattern and levels seen in Figure 5. However, analysis of the pigment data showed that different phytoplankton groups dominated in different areas. The concentration of fucoxanthin (which is associated with diatoms) reveals that diatoms predominate in the southern part of the survey (Figure 10). 19'-Hexanoyloxyfucoxanthin, which is associated with small greens and other non-diatom phytoplankton, shows that these other forms dominate the northern part of the survey (Figure 11). Again, these results are consistent with our previous description of the mooring data. As the bloom decayed, the community became dominated by forms other than diatoms and that this shift occurred in the northern domain first. The other key point is that these phytoplankton pigments have different absorption properties. Given the higher sensitivity of MODIS compared to SeaWiFS, it will be interesting to see if these differences in pigments can be observed in the satellite data. Previous studies have produced conflicting opinions on the feasibility of such measurements, but the importance of such knowledge makes it worth pursuing.

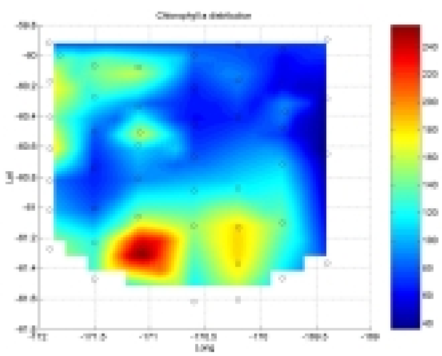

Figure 9. Chlorophyll concentrations derived from High Performance Liquid Chromatography. All concentrations are in ng l^{-1}.

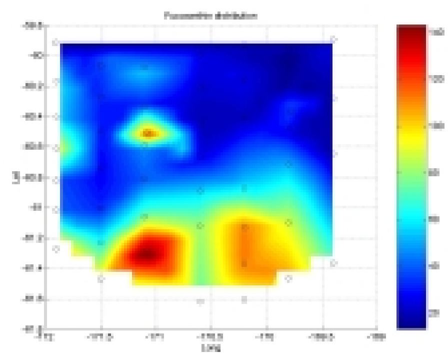

Figure 10. Concentration of fucoxanthin associated with diatoms.

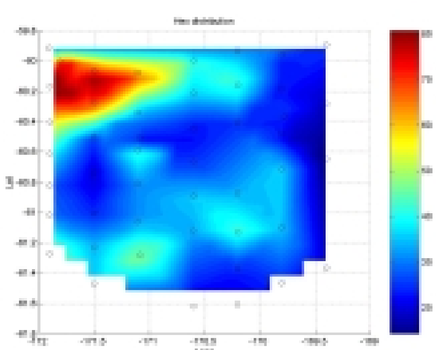

Figure 11. Concentration of 19'-Hexanoyloxyfucoxanthin associated with small flagellates and prymnesiophytes.

All of the mooring, drifter, and TSRB data are available our Web site, http://picasso.oce.orst.edu/users/jasmine/ORSOO

Oregon Optics Cruise

Results from the cruise were presented in our last report. They have formed the basis of two proposals to the National Science Foundation. The first, part of the Coastal Ocean Processes Program (CoOP), will examine processes regulating primary productivity in the nearshore zone. It has been selected for funding and will provide an opportunity for MODIS data product validation. The second, part of the Global Ecosystem Dynamics Experiment (GLOBEC), is under consideration. It would use bio-optical drifters to track water masses in the coastal ocean and explore the time evolution of phytoplankton processes.

Validation Cruise Planning

The validation cruise was planned for October. We are planning to send three people on the cruise to collect Fast Repetition Rate fluorometery data and assist with optical data collection. We will also help with productivity and pigment analyses. However, with the continuing delay in the launch of Terra, it is not clear how this cruise will be used for MODIS initialization. It could still be a valuable exercise, however, as it would provide an opportunity for the MODIS Oceans team to intercalibrate methods as well as support data product development.

Direct Broadcast

The Pacific Northwest presently does not have direct access to the many currently operating and planned Earth observing satellites. Many of the high data rate systems, such as Landsat, ERS-2, SPOT, and Radarsat, are not accessible in real-time for large areas of the North American continent and the eastern North Pacific Ocean. As the next generation of Earth observing satellites is launched, this problem will be exacerbated as most of them will rely heavily on X-band frequencies for data transmission to accommodate high data rate sensors. This includes the NASA Earth Observing System (EOS) missions, Landsat-7, Terra (formerly known as AM-1), PM, and Chemistry, as well as international missions such as Envisat (European Space Agency), and ADEOS-2 (National Space Development Agency of Japan). Presently, the Polar-orbiting Operational Satellites (POES), which are run by NOAA, utilize L-band frequencies for High Resolution Picture Transmission (HRPT) receiving stations. However, the planned National Polar-orbiting Operational Environmental Satellite System (NPOESS) will likely use X-band, beginning with its first mission in 2008. The NPOESS Preparatory Program (NPP) is planning a "bridging" mission which would bring together NPOESS capabilities and NASA science requirements, with a planned launch in 2005. It, too, will probably utilize X-band for data transmission.

The availability of near real-time satellite data is critical to both research and operational applications. It is also essential for many commercial applications. Real-time data can be used 1) to support field programs by determining the optimal locations for sampling, 2) validation of satellite data products, 3) to develop regionally-specific processing algorithms, 4) to enable operational and commercial time-critical applications, 5) to encourage environmental awareness through education and data accessibility.

In partnership with the University of Montana (Steve Running), we propose to develop an X-band EOS Direct Broadcast Facility for the Pacific Northwest to be located at Oregon State University in Corvallis, OR (44.571° N, 123.276° W). We will ship the products directly to facilities at the University of Montana for use in the International EOS Natural Resources Training Center (IENRTC) as well as other applications. The Oregon location, when combined with the X-band sites at the University of South Florida (Frank Müller-Karger, PI) and the University of Hawai'i (Torben Nielsen, PI), will provide wall-to-wall coverage of most of North America and extensive coverage of the central and eastern Pacific, the Gulf of Mexico and the Caribbean, and much of the western North Atlantic. This ground station will initially be configured for MODIS data (on Terra) and will incorporate MODIS on PM, MERIS (on Envisat), and GLI (on ADEOS-II) data.

The ground facility would be configured to produce a subset of both MODIS oceans and land data products within a few minutes to hours of data collection. The data would then be available for browse/order using a Web interface to our data base. Low-level data would be available for a short period of time for those users interested in applying their own algorithms. The initial use of the X-band station will be for MODIS algorithm development and validation. Near real-time data access will be used to select specific sites and locations for field measurements. This is critical for both terrestrial and coastal marine systems where in situ properties can change on small time and space scales. EOSDIS is not designed to deliver data rapidly so direct broadcast remains the only “pipeline” to support time-critical applications. In addition to algorithm validation activities, both OSU and UM have science and application programs that would benefit greatly from near real-time access. We will discuss these activities in detail. Lastly, data products from this X-band station will be “stitched” together with those from UH and USF to provide a near real-time view of the North American continent and its surrounding oceans.

Chemostat Experiments

Using a chemostat that allows the continuous monitoring of passive fluorescence and fluorescence quantum yield under nutrient, light and temperature controlled conditions, we are quantifying the time scales of the physiological response of phytoplankton (as manifested in the chlorophyll fluorescence) to environmental variability. This information is crucial for the development of models of coupled ocean physics and biology as well as for the design and analysis of next-generation in situ instrumentation which rely on passive sensing of phytoplankton.

The main objective during the first phase of our research is to evaluate the range of scales of variability that can be studied by monitoring phytoplankton sun stimulated fluorescence. The results from these studies will help in our interpretation of the scales of variability in phytoplankton fluorescence yield observed in pelagic environments.

Two major questions to be addressed during this phase are:

1. What are the time-lag response of fluorescence to changes in nutrient (nitrogen, phosphorus, and iron), light, and temperature regimes?
2. Is there a correspondence between the magnitude of the fluorescence response and the magnitude or type of environmental change?

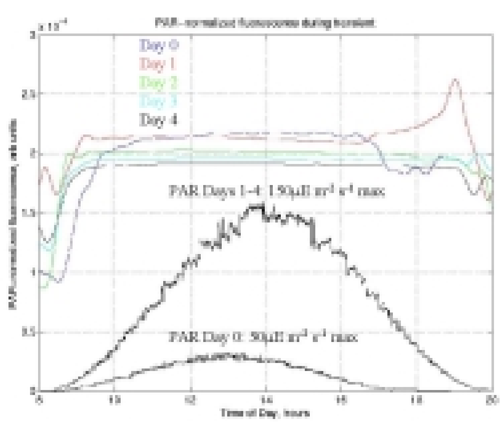

Figure 12 Time series of chemostat measurements. See text for details.

Using our natural fluorescence chemostat (NFC) system, we are attempting to characterize the natural fluorescence signal of phytoplankton cultures with respect to variability in the temperature, pH, nutrient availability and irradiance conditions. We recently have been pursuing two related questions: what is the general character of phytoplankton natural fluorescence over daily cycles and how are these cycles influenced by simple changes in the irradiance regime (such as those resulting from changes in mixed-layer depth and cloud coverage).

In our present experiments we culture the marine diatom *Thalassiosira weissflogii* under conditions of constant pH, temperature and nutrient availability. Irradiance in the chemostat follows a preprogrammed daily sinusoidal model, and over several days the culture reaches a steady state which we define by constancy in the daily chlorophyll concentration. At this steady state we have observed a similar constancy in certain aspects of the natural fluorescence signal. We performed one particular experiment to illustrate that shifts in environmental conditions will be reflected in the natural fluorescence signal of the phytoplankton population. Phytoplankton were grown over several days to a steady state as described above, and then three separate environmental parameters were perturbed in order to induce measurable changes in the natural fluorescence signal. The daily irradiance maximum was increased from 50 to 250 $\mu E\ m^{-2}\ s^{-1}$, the chemostat dilution rate was doubled from 0.1 d^{-1} to 0.2 d^{-1}, and the day length was increased from 10 to 12 hours. Each of these three changes are of sufficient magnitude to induce physiological changes in these phytoplankton cells, and we monitored the natural fluorescence response at 1 Hz resolution as the population responded to these perturbations. The five curves (Figure 12) show the population natural fluorescence normalized to incident irradiance over the daytime light period from 0800 to 2000 for five consecutive days, starting before the transient (day 0) and for four days following (days 1-4). Also plotted are example irradiance profiles for day 0 and the four subsequent days.

We use the fluorescence signal normalized to PAR as an initial estimate of fluorescence quantum yield, and using this parameter we observe three characteristics in this time series which we feel are significant. Firstly, we note a general decrease in the midday plateau of PAR-normalized fluorescence. Chlorophyll concentration in the culture remained very low and roughly constant over the duration of the experiment at around 0.002 $\mu g\ l^{-1}$ and at such low concentrations it is difficult to separate cell specific changes in chlorophyll from population changes. We are addressing such issues of sensitivity, but the observed response observed is consistent with our expectations of light adaptation and will be more thoroughly investigated in upcoming experiments. Secondly, we observe a rapid (< 1 day) response in the initial rise of PAR-normalized fluorescence between 0800 and 1000. We hypothesize that the change in this slope reflects a change in the cell-specific fluorescence yield, and examination of this slope before (day 117) and well after (day 121) the environmental perturbation suggests that approximately 3 days are required for these slowly growing cells to equilibrate with the newly perturbed environment. Thirdly, we observe gross changes in the PAR-normalized fluorescence around 1650 on day 118, which is the first day with a longer day length. Since the population had previously been cultured up until day 0 under 10 hour light conditions (from 0800 to 1800, shown in the figure), we interpret the substantial increase in PAR-normalized fluorescence as an indication that environmental perturbations such as these can be a very significant source of variability in the natural fluorescence signal. Sudden increases in effective day length can occur in regions of strong upwelling, and we are presently conducting experiments which explicitly model such shifts in irradiance in order to determine causal links between irradiance and natural fluorescence.

At this stage, these data have several implications for MODIS. Firstly, even under conditions of varying irradiance levels, the PAR-normalized fluorescence appears to plateau rapidly, within 1-3 hours. Consequently, the variability observed during the hours after dawn may not be significant for a midmorning overpass. Secondly, the variability we do see during the midmorning after an environmental perturbation is in some respects monotonic, exhibiting a regular trend as the culture adjusts to a new steady state. PAR-normalized fluorescence, as measured by our NFC system, looks promising as an indicator of population response to environmental perturbation. Experiments are presently underway to examine the causal link between perturbation in irradiance and to quantify the time scale of the subsequent fluorescence response.

MOCEAN Algorithm Documentation

We revised our algorithm theoretical basis document (ATBD) and provided it to the MODIS project office. Major revisions included a discussion of quality flags, in situ validation data, and development of a research data product for primary productivity.

As part of our joint MODIS/GLI activities, we have developed a complete set of on-line documentation for the MODIS Ocean algorithms. This Web page can be accessed at http://picasso.oce.orst.edu/users/jasmine/MODP/. We have maintained this page in cooperation with the University of Miami. We distributed the Version 2 MODIS Ocean codes to the GLI team and to Dr. Jim Yoder, Univ. Rhode Island, and to researchers working on NPOESS.

We reviewed test data products developed by the University of Miami. There test products were based on SeaWiFS imagery. We provided a mechanism to derive pseudo-fluorescence data as SeaWiFS does not have a channel at 680 nm. After some initial problems, it appears that both the FLH and CFE algorithms are working although the cloud masks still need to be applied. We are working with Bob Evans and Ken Carder to resolve these issues.

EOSDIS Plans

We have continued our work on distributed objects frameworks for EOS data retrieval and analysis. This work was supported through a contract with the Raytheon ECS prototyping activity. Additional reports may be found at http://picasso.oce.orst.edu/users/mark .

We have now put all of our California Current and Southern Ocean drifter on line. Mooring data from Hawai'i and the Southern Ocean are also available, as are the TSRB data sets from the Southern Ocean, Hawai'i, and the Oregon coast. These data can be accessed at http://picasso.oce.orst.edu/users/jasmine/ORSOO . We have also developed a set of Java components to link the data collection and control system for the chemostat with our data base. We are now incorporating Ken Carder's in situ data in our data base as part of an effort to consolidate all of the MODIS Oceans team in situ measurements.

Anticipated Future Actions

- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Complete analysis of data from bio-optical moorings and drifters, TSRB II, and FRR in the Antarctic Polar Frontal Zone
- Complete analysis TSRB II data from the Oregon coast
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors. Establish relationship between fluorescence quantum yield and photosynthetic parameters.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant concern now is the launch date of Terra. The slippage makes it difficult to plan for field programs given that ship schedules are generally locked in one to two years in advance. Obviously, there is no solution to this problem. However, we encourage the Project to continue support for joint field campaigns, including before the cruise planned for October 1999. The silver lining in the delay is that the data processing segment has the opportunity for more thorough tests and to solve problems.